Mobile Ad Hoc Network Routing Protocol Analysis and Its Application to a Programmable Modular Communication System

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Abstract

The Joint Tactical Radio System (JTRS) is a wireless network of programmable modular radios. A mobile ad hoc network (MANET), it aims to enable communication between military users using a single software defined radio to emulate any of several current military radio systems. This paper investigates the strengths and weaknesses of the Zone Routing Protocol (ZRP), one of several routing protocols under consideration by the Internet Engineering Task Force (IETF) for a new mobile network standard, and its application to the JTRS ad hoc network. Simulation results using OPNET 7.0 network simulation software are presented.

1. Introduction

The Joint Tactical Radio System (JTRS) is a joint military acquisition program whose goal is to acquire a family of affordable, high-capacity tactical radios to provide interoperable line-of-sight or beyond-line-of-sight C4I capabilities to all branches of the US military. Figure 1 displays the overall JTRS MANET concept. The radios will cover an operating spectrum from 2MHz to 2GHz and capable of transmitting voice, video and data. The program will develop a flexible hardware baseline that can integrate functional modules and software as required to meet any operational task [1]. As an example, the current version of the JTRS has combined the functionalities of the AN/PRC-113 UHF (HAVE QUICK) radio, a DAMA SATCOM radio, the AN/PRC-104 HF radio and the VHF SINCGARS radio into one. This type of radio is often referred to as a *software defined radio* (SDR) or sometimes a *programmable modular communication system* (PMCS). Perhaps the most aggressive objective of JTRS program is to network the radios in a mobile ad hoc network (MANET).

In a mobile ad hoc network, there is no reliance on preexisting fixed infrastructure, such as a wireline backbone or connectivity via satellite links. The network topology is constantly evolving and changing. The management requirements for organizing and controlling the network are distributed among the radio terminals themselves. Networking in a MANET presents new challenges since both the users and infrastructure are in constant transition.

Previously, most of the interest in MANETs has been from the military. Commercial interest in this area of research is centered around the efforts of the Internet Engineering Task Force (IETF) MANET Working Group whose goals include developing a peer-to-peer mobile routing capability in a purely mobile, wireless domain.

In this paper, we evaluate a particular routing algorithm as it might apply to the JTRS system. Results are obtained by simulating a MANET using OPNET 7.0 network simulation software.

2. MANET Routing

Having a group of nodes (JTRS radios), one task required to allow networking is to formulate a usable routing protocol. Routing can be accomplished by using

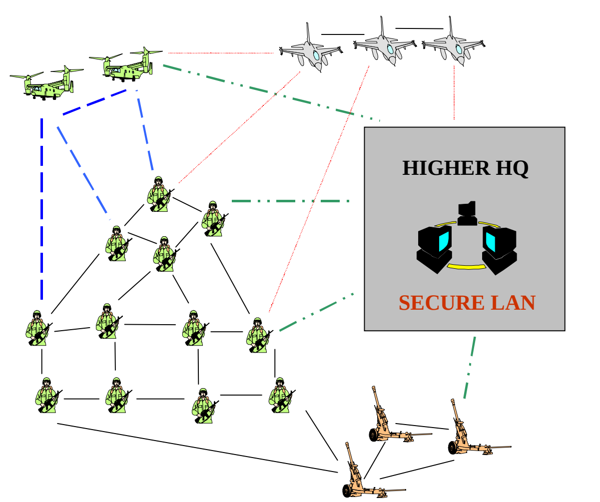

Figure 1: Joint Tactical Radio System (JTRS) Mobile Ad Hoc Network (MANET) Concept

existing algorithms or developing a new one that may be a modification of existing algorithms. A MANET routing protocol is driven by the defining characteristics of the environment which include: a dynamic topology, limited bandwidth, variable capacity, asymmetric links, energy constrained operation, wireless vulnerabilities, and limited physical security. Conventional routing protocols have proven to be poor performers in the mobile environment, due to several factors: transmission between two hosts over a wireless network does not necessarily work equally well in both directions; many of the links between routers seen by the routing algorithm may be redundant; periodically sending routing updates wastes network bandwidth and battery power; and conventional routing protocols are not designed for the type of dynamic topology changes that may be present in ad hoc networks [2]. Mobile IP was developed as an adaptation of conventional routing protocols to meet the needs of MANETs. Although Mobile IP is a useful protocol for stub networks off a fixed infrastructure, in an ad hoc network there is no home agent or foreign agent to support this service.

This paper investigates the advantages and disadvantages of the Zone Routing Protocol (ZRP), developed by Haas and Pearlman [3].

3. Zone Routing Protocol (ZRP)

The ZRP protocol incorporates a localization approach to routing. It incorporates a hybrid protocol that exploits the benefits of both a reactive and a proactive protocol [3]. As depicted in Figure 2, each mobile node has a proactive routing zone around it that is dictated by an adjustable zone routing radius (ρ). The zone routing radius determines which other nodes are within the local area (zone) of a given node, and is the same as the maximum allowable hop count. In Figure 2, nodes B, C, D, E and F are in Zone A if the zone routing radius is ρ = 2. This means that they all lie within two hops of node A. All nodes in zone A are subject to the Intrazone Routing Protocol (IARP).

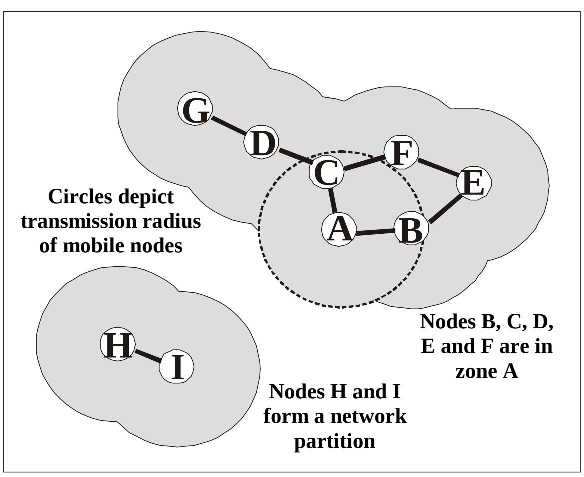

Figure 2: ZRP Example: Zone Routing Radius ρ=2

IARP is responsible for maintaining routes within each node's routing zone through periodic routing table updates. This is typically accomplished using a wide range of traditional distance vector or link-state protocols [4]. Although there are tradeoffs involved in IARP protocol selection, experience has shown that the overall performance of ZRP is not affected by this choice [5]. Figure 3 is an illustration of the ZRP architecture. As shown, IARP relies on the Neighbor Discovery/Maintenance Protocol (NDM) to provide current status of a node's neighbors. This NDM service is provided by the MAC/link-layer protocols. The overhead generated with IARP is a function of the number of nodes in the routing zone (node density) and the zone routing radius [1]. Node density is a function of transmit radius.

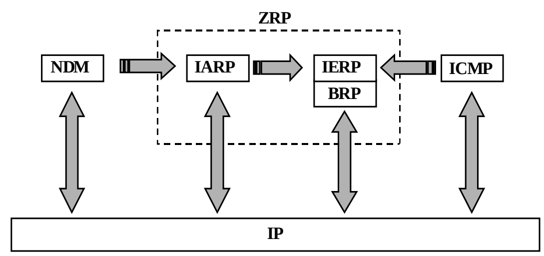

Figure 3: ZRP Architecture

Routing outside the zone is done based on a reactive or on-demand approach using Interzone Routing Protocol (IERP). Some of the functions of IERP including bordercasting, route accumulation, and query control, are performed by a special component of IERP called the Bordercast Resolution Protocol (BRP). IERP queries through the network, although global in nature, are expedited by using proactive routing zones. Instead of having to reach each node, the discovery process must merely touch each routing zone to discover the targeted

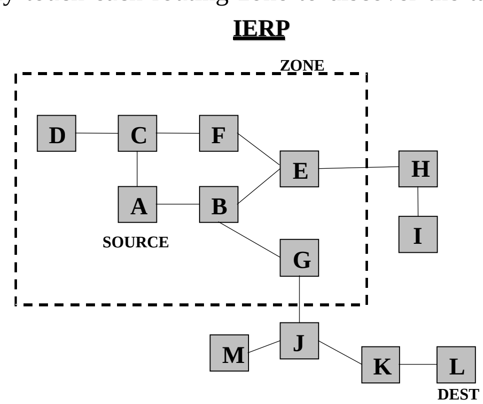

Figure 4: IERP Search Using BRP

node. Figure 4 illustrates the discovery process used in IERP. Node A has a datagram to send to L. As depicted, L is not in A's routing zone. Node A bordercasts (using BRP) the route query to all peripheral nodes (D, E, F, and G). Each peripheral node, in turn, checks its routing table (IARP) for L and none of them have it. Each peripheral node now bordercasts (BRP) to its own peripheral nodes. For example, Node G conducts a table look up from its zone table (IARP) and is unable to locate node L. A bordercast (BRP) is initiated by node G, and K is able to check its table (IARP) and quickly respond (IERP) with the location of node L. The return route is identical to the query route.

Routing failures are detected and repaired reactively by IERP. The repair process initiated by IERP is almost identical to the discovery process. IARP utilizes proactive route failure detection, which is triggered in response to a node leaving the source node's zone.

A mathematical expression for the zone radius for optimum performance has not yet been determined [5]. Even with perfect knowledge of all network parameters, computation of an optimal routing zone radius is not a straightforward mechanism. As depicted in Figure 5, a simple approach is to adjust the zone routing radius until the setting for minimum ZRP overhead traffic is achieved. In this figure, the optimum region resides between the IARP- and IERP- dominated regions. In other words, the ratio between IERP to IARP (IERP/IARP) should be as close to unity as possible for optimization. The general rule-of-thumb is that a sparse network favors a large routing zone and a dense network favors a small routing zone.

4. Simulation and Results

The network configuration used in this scenario was designed to mirror the tactical use of JTRS by individual Marines. The network implementation was designed to emulate a Marine rifle platoon operating with JTRS squad-level radios operating in a 1 km × 1 km area. Although a Marine rifle platoon operates with 42 personnel, 32 nodes were utilized in this work, which provides a reasonable representation of this combat force. The number of nodes was kept to 32 to reduce the demand on the computing platform available for simulation and to reduce simulation time. The 32 MANET nodes each represent a Marine rifleman with individual movement and data exchange capabilities. In a rapidly developing combat situation, each Marine would transmit and receive information to his fellow Marines for control and situation awareness. Each MANET node moves randomly across the x-y plane and communicates in a random fashion to mimic combat maneuvering and tactical data traffic. It is important to note that due to the limitations of the current ZRP configuration, the MANET nodes do not move in tactical formations. Each node is an independent random variable for both movement and traffic placed on the net.

The network of JTRS nodes is analyzed using the OPNET 7.0 network simulation tool [6]. A ZRP OPNET model provided by Haas and Pearlman was slightly modified and used to evaluate the routing protocol. The focus of this analysis was to evaluate the efficiency and reliability performance of ZRP. Node velocity, zone routing radius, message traffic and transmit power (radius) were varied, and the amounts of IARP and IERP traffic overhead, link failures and link efficiency were measured.

Figure 6 is a plot of ZRP overhead generated as a function of zone routing radius. As zone routing radius increases, more nodes will become a part of the local zone, rapidly increasing local zone (IARP) overhead. Concurrently, there are fewer nodes outside the local

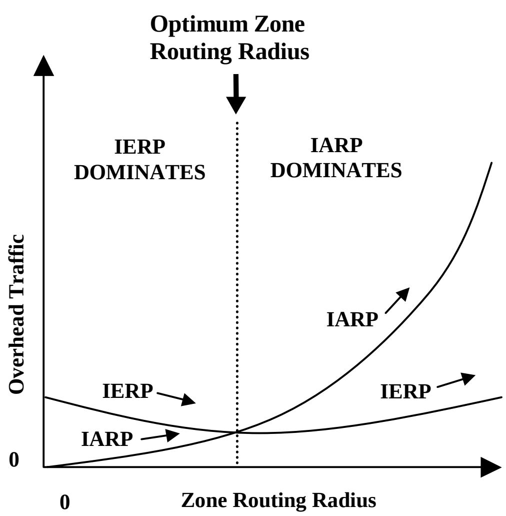

Figure 5: ZRP Zone Routing Radius Optimization

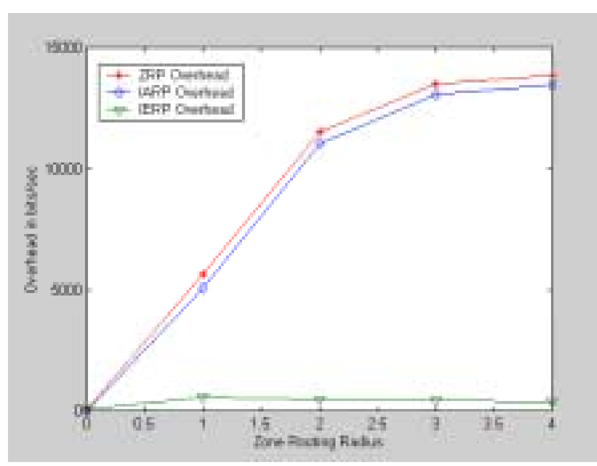

Figure 6: ZRP Overhead with Changing Zone Radius

zone, and on average, there are fewer attempts to communicate with a node outside the local zone: IERP drops somewhat. It was found that node velocity had little or no effect on ZRP overhead. This was due to the short length of transmissions (bits) in the scenario and the relatively low node velocity utilized. It is expected that with longer transmissions and/or higher node velocities, the IERP overhead would increase as links get broken/repaired.

Figure 7 shows the effects of increasing zone routing radius on the amount of overhead generated in the local zone (where IARP applies). This figure displays the IARP traffic generated per node (packets/sec) for the Marine scenario with JTRS transmission radii of 0.1 km and 0.2 km. From this plot, as the zone routing radius is increased, the number of nodes in the local area increases, as expected. In addition, as the transmission radius (tr) increases from 0.1 km to 0.2 km, the IARP overhead increases since the size of the local zone has increased and more nodes fall within it. These curves are compared to scenarios run by Haas et al [5] which uses a much greater number of nodes (200-1000) providing a neighbor density (number of nodes that can be reached in one hop) of 3 to 5. The 1 km × 1 km scenario provided on average between 3 and 5 neighbors with a zone routing radius of 1.

Figure 8 is a plot of link failure percentage versus zone routing radius, for the Marine scenario with a node velocity of 0.2 km/hour, a transmission radius of 0.2 km and a simulation duration of 15 minutes. With a zone radius of 0 (all routing handled by IERP), the failure rate was 0.75 failures/sec, and increasing the zone radius to one reduced failure rate to 0.6. As the zone radius is increased, the failure rate becomes nearly constant, due to the small size of the network nullifying the effects of increased zone radius. Compare this to the curve from Haas [5] that simulated a 1000 node network. For this curve, as the zone radius increases, more nodes fall into

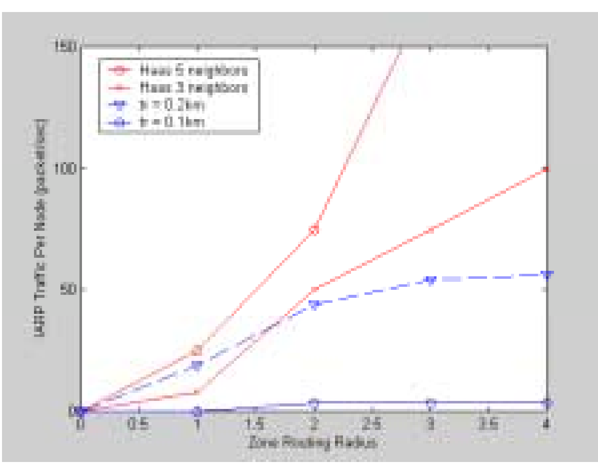

Figure 7: IARP Overhead with Changing Zone Routing Radius

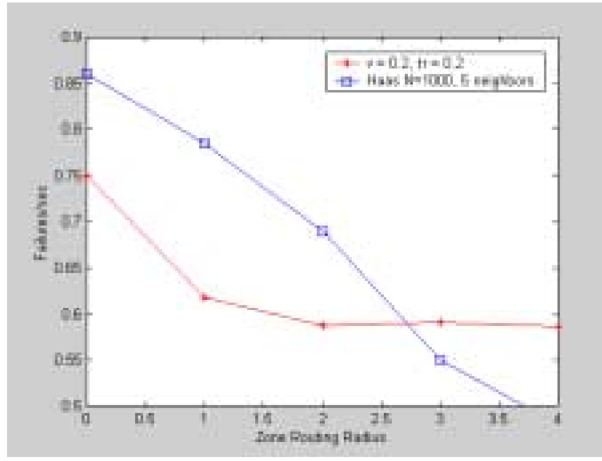

Figure 8: Link Failure Percentage with Increasing Zone Routing Radius

the local zone, improving reliability. The ZRP mechanism that increases the reliability is the BRP: instead of having to route through each node to the destination, BRP provides an optimum routing mechanism by exploiting available IARP link-state information in each routing zone for optimization, thus decreasing hop counts to the destination. The Haas example illustrates the impact of neighbor density that amplifies the routing optimization, which can be achieved from the proactive routing zone cache of IARP. Neighbor density is increased by increasing the transmission radius of each MANET node. With increased neighbor density, the potential for link failure increases (inability to establish a route) due to node movement, channel interference and other factors associated with links between nodes.

Finally, Figure 9 displays link failure percentage as a function of node velocity, with zone routing radius fixed at two. In this case, the transmission radius was 0.2 km and the velocity was varied from 0 to 0.8 km/hour. With all nodes stationary (velocity = 0), the failure percentage was ~57%. Increasing node velocity caused an increase in failure percentage, due to shorter periods of route stability. There was an unexpected deviation from this trend at a velocity of 0.8 km/hour, and a second simulation yielded very similar results. A third simulation was run with a smaller transmit radius (0.1 km), providing a fairly constant link failure percentage (~95%), which was inconclusive. The Marine scenario failed to produce distinct ZRP behavior in this case.

5. Conclusions

The results of this paper provided a snapshot into the performance of ZRP in a small generic mobile ad hoc network chosen to represent a future JTRS architecture on the relative scale of a single Marine rifle platoon operating in a one square kilometer area of operation.

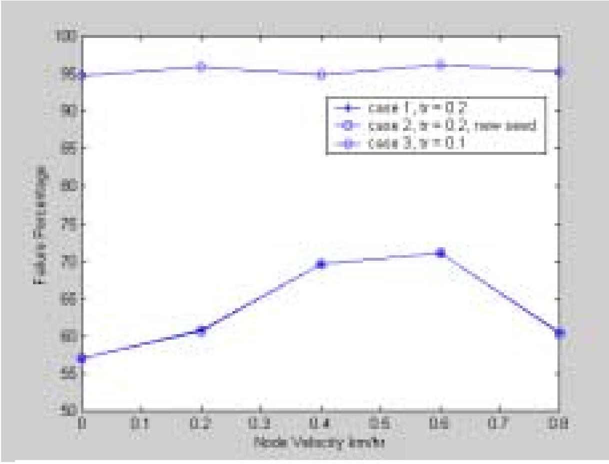

Figure 9: Link Failure Percentage with Changing Velocity: Zone Routing Radius = 2

The complete behavior of ZRP was not demonstrated in the Marine scenario due to the limited number of nodes (32), the low traffic generation, and the small geographic axis boundaries due to performance limitations of the computing platform utilized. Previous results reported by Haas and Pearlman were used as a rheostat to scale the results from the Marine scenario to the behavior of ZRP in that of a much larger network with MANET environment parameters outside of the capabilities of this work.

The traffic overhead behavior of ZRP in the Marine scenario was consistent with a hybrid MANET protocol. With constant velocity and average neighbor density (primarily dictated by transmit radius), the zone routing radius proved to be the critical parameter dictating the amount of ZRP overhead generated in the Marine scenario. IARP overhead traffic increased rapidly as the zone routing radius is increased but is unaffected by node velocity. IERP traffic overhead is driven by the traffic generation of the source nodes and caused ZRP overhead fluctuations in the presence of changes in velocity. IERP is responsible for repairing routes, and this activity is slightly increased as a result of route instability introduced by velocity.

ZRP link performance was improved in the Marine scenario by increasing the zone routing radius and appears to be directly related to node velocity in the Marine scenario. However, the results were inconclusive because of the relatively small network simulated and low node velocities, again due to limited computing power. In general, as the node velocity increases, the ability to maintain link stability decreases. The time to transmit a message over the link becomes a problem with increased velocity due to short periods of route stability.

ZRP is a simple hybrid MANET protocol that has a great deal of potential for JTRS. However, more in depth study and analysis is required to further explore its capabilities.

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